ANALOG DEVICES

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AN-219
APPLICATION NOTE

Electronic Adjustment Made Easy with the TrimDAC

by Walter Heinzer and Joe Buxton

The TrimDAC® is a multi-channel d/a converter designed specifically for adjusting gains and dc levels in electronic circuits digitally and without moving parts. It combines many of the properties of the adjusting pot(entiometer) with the prospect of hands-off automatic adjustment and high reliability. The highly desirable attributes of TrimDACs include small package size, many devices per package, serial interface (reduces pin count) and low power dissipation. TrimDACs in electronic adjustment reduce cost in two ways: the higher speed of adjustment under software control saves time and capital investment; and the device itself is quite cheap.

Most designers of new circuit designs would like to avoid the once-ubiquitous variable resistor because of its mechanical sensitivity, relatively wide absolute tolerances, and high labor cost. But there is generally a need for factory adjustments and calibrations in electronic equipment. Even digital products need a power supply adjusted or calibrated to a specified tolerance. And many electronic systems are connected to real world sensors or output devices in *systems* that need calibration. A key issue facing engineers who design such systems is cost reduction of factory calibration and field maintenance.

Electronic factory-calibration of chips by semiconductor manufacturers is already widely used; calibration and adjustment problems are solved on (and with) integrated circuits by autozero, self-calibration, Zener-zap, fuse link, EPROM and laser trim. Something akin to this in larger-scale real-world systems is highly desirable.

Recognizing this problem, we sought to design products to fill the need for digitally adjustable electronic devices to automate, speed up, and eliminate manual and mechanical adjustments.

For example, consider the CRT display; curvature aberrations in the manufacturing of glass tubes require that the elements of focus (convergence & color purity) be individually adjusted, especially for high-resolution displays. Since the convergence adjustment of CRT display systems with resolutions of more than 1,000 lines requires that 6 to 8 variable-resistor adjustments be made in high-volume production—currently by robot-controlled screwdrivers—displays are ideal candidates for electronically controlled adjustment devices. The TrimDAC offers an attractive alternative to this mechanical adjustment approach. Previously a labor- (human or robot) intensive process taking minutes, the operation now can be done in seconds.

VOLTAGE ADJUSTMENT, THE FIRST GENERATION

The first TrimDAC, the DAC-8800, is a monolithic CMOS IC with all the ingredients necessary for general-purpose dc voltage setting. It contains eight unbuffered voltage-output d/a converters in a 20-pin skinny DIP package (Figure 1). The output voltage range, unipolar or bipolar, can be independently set for each group of four DACs. Output voltage ranges are established by the choice of high- and low- external-reference inputs. The 8-bit DACs provide 256 voltage levels within each range.

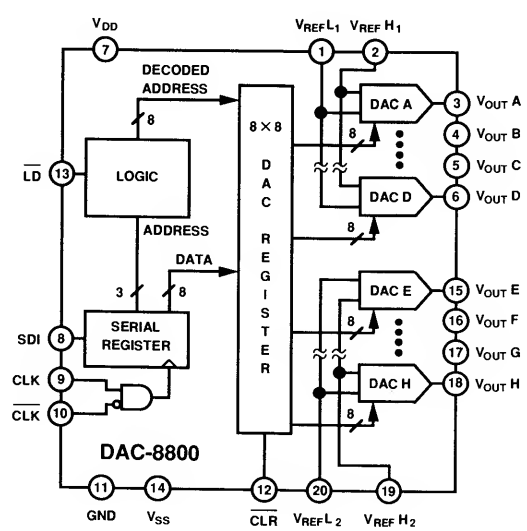

Figure 1. DAC-8800 Block Diagram. Shared References Determine Output Voltage Range.

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A TTL-compatible 3-wire serial interface loads the contents of the eight internal DAC registers. These can all be set to zero by an asynchronous Clear (CLR) input, very handy for system power-up. An internal regulator provides TTL compatibility over a wide range of V_{DD} supply voltages. Single-supply operation is available by connecting V_{SS} to GND. The device achieves its performance and flexibility with a low 24 mW of dissipation.

The output voltage of each DAC is changed by clocking an 11-bit word (3 address bits, 8 data bits) into the serial shift register. The internal logic decodes the three address bits to establish which internal DAC register will receive the 8 bits of data from the serial register during the Load (LD) strobe. One DAC is updated with each LD strobe. At the maximum clock rate of 6.6 MHz, all eight d/a converters can be loaded in as little as 14 microseconds.

The output voltage range is determined by the external input voltages applied to V_{REFH} and V_{REFL} (Figure 2). If V_{SS} is negative, V_{REFL} may be set to a negative value; this results in a programmable bipolar range of output voltages. The relationship between V_{OUT}, and V_{REFH}, V_{REFL}, and the digital input, D (a base-10 integer between 0 and 255), is:

$$V_{OUT}(D) = (D/256)(V_{REFH} - V_{REFL}) + V_{REFL}$$

The DAC-8800 is tested for operation with $V_{DD} = 12$ V and $V_{SS} = 0$ V or -5 V. However, it was designed to operate from a wide variety of available supply-voltage combinations. Here are some typical pairings: V_{DD}, V_{SS} = +15 V, 0 V; +12 V, 0 V; +12 V, −5 V; +5 V, −5 V; +5 V, −12 V; +5 V, 0 V.

The primary application of the DAC-8800 is with fixed reference inputs for dc voltage setting. Outputs may be applied directly to high-impedance circuits—or to external op amps for buffering.

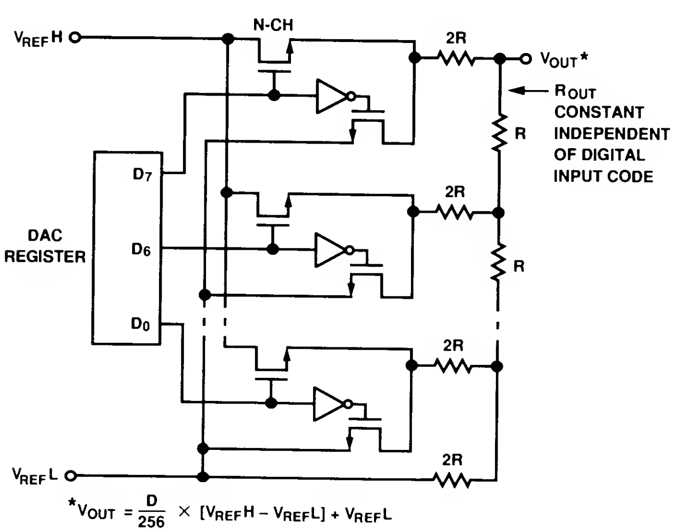

Figure 2. Simplified Equivalent Voltage-Switching DAC Circuit. The Output Resistance Remains Constant at a Nominal 11 kΩ.

ADDING GAIN: THE SECOND GENERATION

Second-generation TrimDACs, such as the DAC-8840 and DAC-8841, solve the problem of replacing variable resistors for adjusting ac or varying dc voltages—for example, in audio volume control. Other common applications where ac signals must be attenuated include some circuits found in video displays, projection-TV displays, instrumentation, oscilloscopes, medical gear, modulation circuits, modems, and so on.

The DAC-8840 contains a multiplying DAC structure with four-quadrant multiplying capability. Figure 3 shows the connection of one of the eight independent channels of the DAC-8840. This multiplying channel has a 1-MHz bandwidth for ±3-V input signal levels while operating from ±5-V supplies. A typical signal channel has 0.01% total harmonic distortion and can slew at 2.5 V/µs. Because the output amplifier is connected in a differencing (push-pull) configuration, the gain for signals applied to V_{IN} can range from full-scale positive to full-scale negative, depending on the applied digital (offset binary) word. The magnitude of the binary word corresponds to the wiper position of a pot, with zero output at half-scale; a Preset control input sets all DACs to this "zero" position. Figure 4 describes this serial input CMOS octal D/A converter in greater detail.

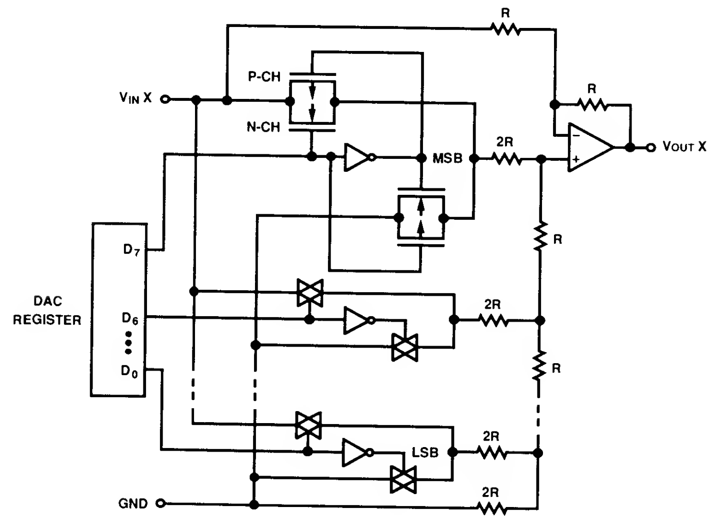

Figure 3. One Channel of the Four-Quadrant Multiplying DAC-8840.

The gain transfer function of a DAC-8840 channel is:

$$V_{OUT}(D) = (D/128 - 1)\ V_{IN}$$

where D is the value of the binary input, a decimal integer between 0 and 255. At full-scale, $V_{OUT} = 127/128 \times V_{IN}$; when $D = 128$ (also the Preset condition), V_{OUT} equals zero volts; and when D = zero, $V_{OUT} = -V_{IN}$.

In the DAC-8840, eight DAC registers store the output state; they are updated from an internal serial-to-parallel shift register loaded from a standard 3-wire serial-input

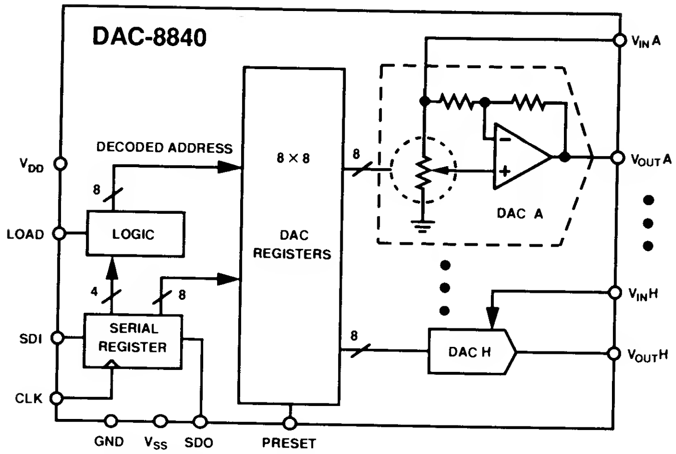

Figure 4. DAC-8840 Block Diagram. Note the 3-Wire Input and Serial Data Output Pin (SDO) for Daisy-Chaining Additional Packages.

digital interface. The data word clocked into the serial-input register (SDI) consists of 12 bits; the first four determine the address of the DAC register to be loaded with the 8 data-bits. A serial data output pin at the other end of the shift register (SDO) allows simple daisy-chaining in multiple DAC applications without additional external decoding logic (Figure 5). The fourth address bit, which decodes as a NOP for the package, makes it possible to select a single DAC in one of the packages to be updated when all the packages receive the common LD DAC strobe signal.

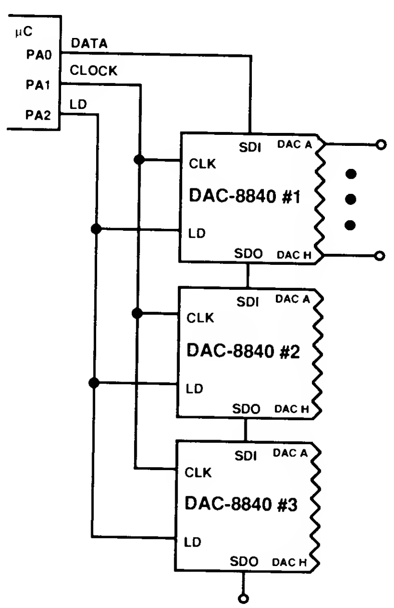

Figure 5. DAC-8840s in a Serial Daisy Chain Minimize Chip Decoders.

The DAC-8841, a mask option of the DAC-8840, offers an ideal octal DAC for +5-V single-supply applications. The DAC and amplifier of each channel are configured as shown in Figure 6, with the amplifier connected for a non-inverting gain of two. This configuration is a 2-quadrant multiplying arrangement with a 1-MHz bandwidth. AC signals applied to the V_{IN} terminal can be attenuated to zero or amplified by a factor of up to two, with 256 possible level settings from zero to 2 × (255/256) V_{IN}:

$$V_{OUT}(D) = 2 \times (D/256) \times (V_{IN} - V_{REFL}) + V_{REFL}$$

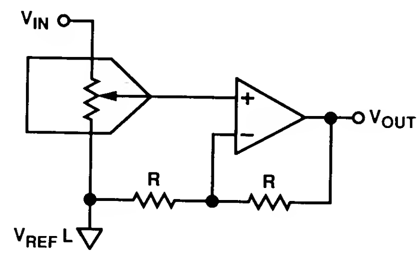

Figure 6. Internal Connections of the +5-V-only DAC-8841.

VARIABLE RESISTORS VERSUS TRIMDACS

From the above overview of the DAC-8800 and DAC-8840/41 TrimDACs, we can compare them to mechanically variable resistors (pots), reviewing the strengths and weaknesses of each.

Advantages of TrimDACs over Potentiometers: Better mechanical stability, improved product life, improved temperature coefficients, smaller size; computer control can eliminate technician costs; remote operation, constant output resistance, and low output resistance with low power dissipation.

Advantages of Potentiometers over TrimDACs: Voltage range usually much greater, no separate power supply required, simple human interface, no memory required, no "zipper noise" (the sound heard when using a DAC to adjust audio levels).

Another useful advantage of the potentiometer at present is a nonvolatile memory. That is, in a vibration-free environment, the wiper of the potentiometer stays where it was last set, even with the power off. The TrimDAC devices described here do not contain nonvolatile memory; for them, the required memory is generally supplied by system E^2PROM. Since in many of today's systems a low-cost high-density E^2PROM holds system set points for current time, date, mode, parameters and so on, it is an easy matter to share this nonvolatile memory with the TrimDAC calibration set points; they are reloaded at system powerup.

TYPICAL APPLICATIONS

In professional audio equipment, voltage-controlled amplifiers (VCA) are used to set gain, fade, pan and mix signals. The dc control inputs of these VCAs are ideally controlled by the DAC-8800 (Figure 7). The addition of the capacitor at the VCA voltage control port, VC, helps to limit the slew rate, reducing the clicking to a subaudible level. One DAC-8800 can control 8 channels of logarithmically set gain and attenuation levels.

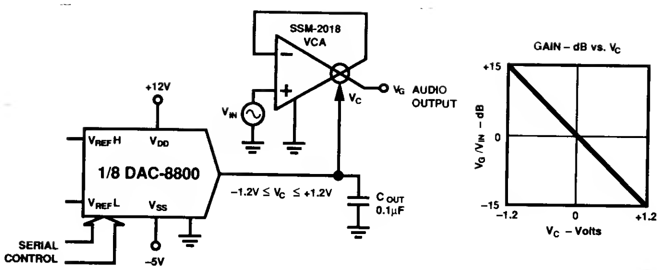

Figure 7. Setting Gain of a Voltage-Controlled Amplifier in Professional Audio Equipment. One DAC-8800 Can Serve 8 Channels. The Damping Capacitor at the Voltage-Control Point Minimizes Zipper Noise by Slowing Rates of Gain Change to Subaudio Frequencies.

Figure 8 shows a selection of output configurations of a DAC-8800, including simple buffers, summing circuits with coarse/fine control, and adding gain for increased output swing. A DAC-8800 can be used in system offset nulling by connecting its output to the summing node of any convenient op amp, using an appropriate value of summing resistance or a T-network.

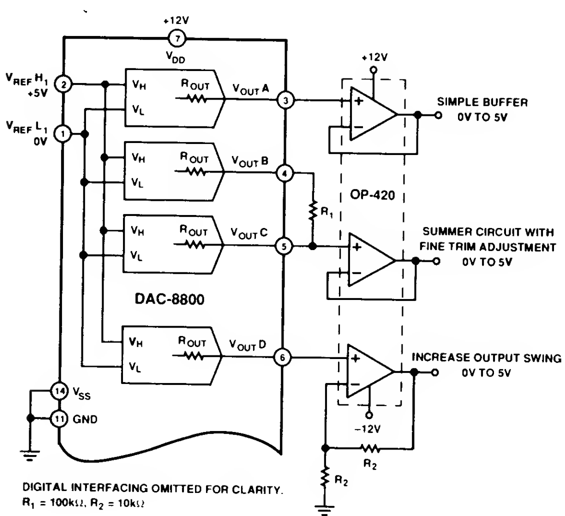

Figure 8. Some Ways of Buffering the DAC-8800 Output.

For video convergence and deflection control, especially in multi-sync displays, the DAC-8840 can be used to adjust the sawtooth waveform amplitudes, their reference bias voltages, and the parabolic waveforms used to linearize them as they are summed together to drive the CRT deflection. Figure 9 shows a block diagram of a typical arrangement.

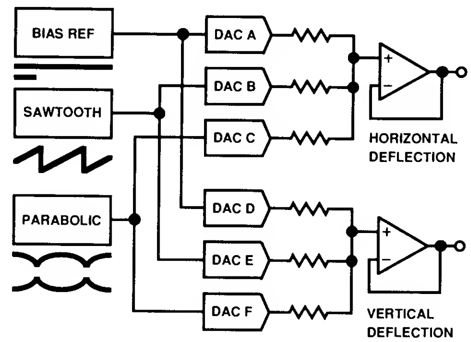

Figure 9. DAC-8840's Four-Quadrant Multiplying Capability Simplifies Amplitude Adjustment of Waveform Components in Video Deflection.

Availability

The 20-pin DAC-8800, and the 24-pin DAC-8840 and DAC-8841 are available for two temperature ranges—extended industrial (−40°C to +85°C) and military (−55°C to +125°C). Packaging includes plastic and ceramic DIPs and SOL surface-mount packages.